VERNIER SOFTWARE

PHYSICS PROGRAMS FOR APPLE COMPUTERS

COPYRIGHT 1983

64K

David L. Vernier
2920 S.W. 89th Street
Portland, Oregon 97225
(503) 297-5317

```
*********************
*                   *
* WAVE ADDITION II  *
*                   *
*********************
```

Wave Addition III
15.00 +4.00 for shipping

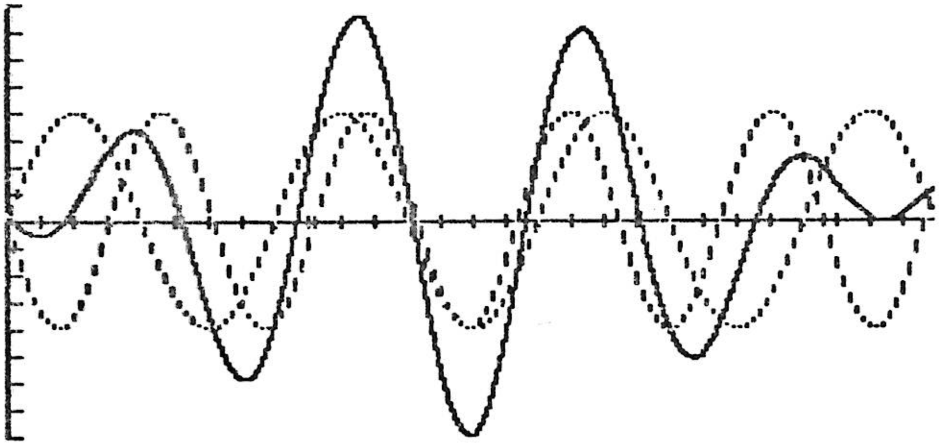
User's Manual

Teacher's Guide

Modifications

Program Design Notes

Table of Variables



Karen Bosher
3.2
SAT
INVOLVED WITH
ACTIVITIES

WAVE ADDITION II

USER'S MANUAL

WAVE ADDITION II is a program designed to demonstrate how waves add together according to the superposition principle. Many interesting physical phenomena may be demonstrated, including beats, constructive and destructive interference, formation of musical notes, and Fourier synthesis.

The program may be run in 10 different modes. Some of these modes are demonstrations in which the computer adds pre-programmed waves in order to demonstrate a specific wave phenomenon. In other modes, the operator selects the waves to be added. After the waves to be added are selected, each wave is drawn and then the result of the superposition is displayed.

LOADING THE PROGRAM:

The program requires a 48K Apple II Plus with the Applesoft language or an Apple IIe. It is on a 16 sector DOS 3.3 diskette. To run the program simply turn on or "boot" the computer with the diskette in drive one. Alternatively you may type "RUN HELLO".

USING THE PROGRAM:

When you run the "menu" below is displayed on the screen:

SELECT MODE:

0 = GENERAL INSTRUCTIONS
1 = DEMO OF ADDITION OF 2 WAVES
MIXED TIDE 2T → 2 = ADDITION OF TWO WAVES ← set [illegible] of [illegible] to addition of $f = 5$ $A = $ [illegible] $\varphi = 0$
for resultant wave alone
3T → 3 = DEMO OF BEATS
4 = ADDITION OF 4 WAVES
5 = EXPLANATION OF FOURIER SYNTHESIS
6 = DEMO SYNTHESIS OF A SAWTOOTH WAVE
7 = DEMO SYNTHESIS OF A SQUARE WAVE
8T → 8 = DEMO SYNTHESIS OF A TRIANGULAR WAVE
9 = FOURIER SYNTHESIS OF NINE WAVES
10 = QUIT

Abbreviated instructions for using the program may be displayed on the screen by selecting mode 0 from this menu. These instructions should be enough for anyone who has done some experimenting with the program. The following is a more detailed explanation of the program which should be especially helpful to anyone using the program for the first time.

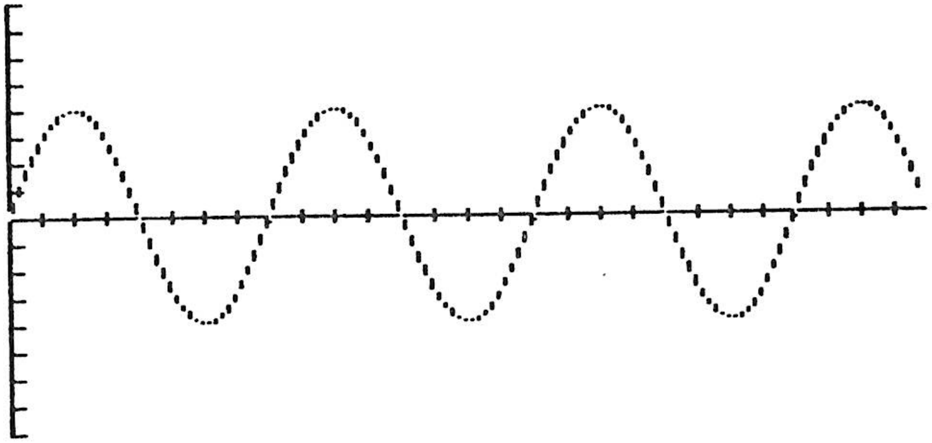
Any of the 11 modes may be selected by pressing the appropriate number key and then the RETURN key. After the operations of that mode are completed, the program will return to the menu.

NOTE: There are some special options which may be selected at the time of choosing the mode of operation. The options are explained at the end of the User's Manual.

In each mode (except modes 0 and 5) waves will be added to the "fundamental" wave. The fundamental wave always has the following values:

frequency = 10 Hertz
amplitude = 40 units
phase angle = 0 degrees

The fundamental will look like this when draw on the screen.



The waves to be added to this fundamental wave are different in each mode. The modes are described below:

MODE 1 - Demonstration of the addition of 2 waves

In this mode (and all others with "DEMO" in their title), the computer selects the wave to be added to the fundamental wave. This mode is intended as a simple demonstration of how the program may be used to show wave addition graphically. The wave programmed to be added to the fundamental has the following values:

frequency = 20 Hertz
amplitude = 40 units
phase angle = 180 degrees

This wave has a frequency twice that of the fundamental and the same amplitude. It is also originally 180 degrees out of phase with the fundamental.

MODE 2 - Addition of 2 waves

In this mode the operator is asked to enter the values for the frequency, amplitude, and phase angle of a second wave to be added to the fundamental. You should enter the three values, separated by commas, and then press RETURN. The frequency, amplitude, and phase angle of the fundamental wave are shown on the screen for comparison. The maximum value allowed for the frequency is 80 (Hertz) and the largest amplitude allowed is 80 units.

MODE 3 - Demonstration of beats

This mode is intended to demonstrate how beats are formed by the addition of two waves. The computer selects a wave with the following parameters to be added to the fundamental:

frequency = 13 Hertz
amplitude = 40 units
phase angle = 180 degrees

Notice that the second wave is the same amplitude as the fundamental, but has a slightly higher frequency. The two waves start completely out of phase.

MODE 4 - Addition of 4 waves

This mode is similar to mode 2 except that you are asked to enter the values for frequency, amplitude, and phase angle for three waves. All three of these waves will then be added to the fundamental. The maximum value allowed for the frequency is 80 (Hertz) and the largest amplitude allowed is 80 units.

MODE 5 - Explanation of Fourier synthesis

This mode displays a brief explanation of Fourier synthesis, which is used in the last 4 modes of operation. This mode does not add waves.

MODE 6 - Demonstration of synthesis of a sawtooth wave

This mode uses the principle of Fourier synthesis to construct an approximation of a sawtooth wave. Eight waves are added to the fundamental wave. Their values are given by:

frequency = (fundamental frequency) * J
amplitude = (fundamental amplitude) / J
phase angle = 0 degrees

where J = 2,3,4,5,6,7,8,9.

That is, all of the harmonics up to the 9th are added. The amplitude decreases as the harmonic number increases.

MODE 7 - Demonstration of synthesis of a square wave

This mode uses the principle of Fourier synthesis to construct an approximation of a square wave. Four waves are added to the fundamental wave. Their values are given by:

frequency = (fundamental frequency) * J
amplitude = (fundamental amplitude) / J
phase angle = 0 degrees

where J = 3,5,7,9.

That is, all of the odd harmonics up to the 9th are added. The amplitude decreases as the harmonic number increases.

MODE 7 - Demonstration of synthesis of a triangular wave

This mode uses the principle of Fourier synthesis to construct an approximation of a triangular wave. Four waves are added to the fundamental wave. Their values are given by:

frequency = (fundamental frequency) * J

$$\text{amplitude} = \frac{\text{(fundamental amplitude)}}{J^2}$$

The phase angle alternates between 0 and 180 with each odd harmonic (third harmonic - 180, fifth harmonic - 0, seventh harmonic - 180, ninth harmonic - 0).

where J = 3,5,7,9.

That is, all of the odd harmonics up to the 9th are added. The amplitude decreases considerably as the harmonic number increases.

MODE 9 - Fourier synthesis of up to nine waves

This mode asks the operator to input amplitude values for the second through ninth harmonics to be added to the fundamental. The computer will ask for the amplitude values one at a time. If you do not want to add the particular harmonic at all, enter 0 as the amplitude. The maximum allowed amplitude is 50 units. The phase angle will be assumed to be zero in all cases.

MODE 10 - Quit

Choosing this mode will end the program. It also restores the computer's internal pointers so that you can run other programs.

The program's graphics proceed in the same manner regardless of the mode chosen (except modes 0 and 5, which have no graphics). The screen is cleared and vertical and horizontal scales with marks every 10 units are drawn. Next, the fundamental wave is drawn and its frequency, amplitude, and phase angle are printed at the bottom of the screen. Each wave to be added to the fundamental is then drawn, one by one, with wave parameters listed at the bottom of the screen as it is being drawn. If a wave to be added has an amplitude of 0, it is not drawn. The computer now calculates the superposition of all the waves and draws it out on the screen. On a color monitor, each wave drawn is in a different color.

The program will now allow you time to look at the results. This message will be displayed at the bottom of the screen:

```
        PRESS RETURN TO RETURN TO THE MENU,
        OR ENTER:  R=REDRAW  E=REDRAW EXPANDED
```

If you simply press the RETURN key the program will return to the main menu. You can rerun the program in any mode you wish.

If you press the "R" key and then the RETURN key, the entire wave diagram will be redrawn just as before.

If you press the "E" key and then the RETURN key, the whole process of adding the waves will be repeated with a horizontal scale which is double the original scale. The "tick marks" along the center line which represent 10 units will be half as far apart as before. Twice as much of the wave can be seen on the screen.

SPECIAL OPTIONS:

At the time you select the mode of operation from the main menu, you may elect one of two special options which affect how the waves are displayed. The first special option is "S" for "stop". To select it enter a second character of "S" as you select the mode. For example, if you want to choose this option with mode 1 enter "1S" from the main menu. This option causes the program to stop after each wave is drawn and wait for a keypress before drawing the next wave. The other special option is "T" for "total". You choose this option by entering a "T" as a second character as you select from the main menu. This option causes the program to draw the superposition of the waves on a separate screen after each wave is added. This is especially helpful when many waves are to be added, as in modes 6-9. You can then see the gradual change in the summation wave as each component wave is added.

TERMINOLOGY USED IN THIS PROGRAM:

Here are some definitions of terms used in this program:

Amplitude: A measure of the maximum displacement (height) of a wave.

Frequency: The number of wave peaks that pass by a point in a unit of time. It is usually measured in Hertz (1 Hertz = 1 cycle/second).

Phase angle: Indicates to what extent two waves are 'in step' at the start of the program. It is measured in degrees. If two waves have the same phase angle, they start totally in phase. If they differ in phase angle by 180 degrees, they start totally out of phase (one going up as the other is going down).

Superposition: The addition of waves. Waves are added by vector addition of the displacements along the wave.

Fundamental: The lowest frequency produced by a musical instrument. In this program the first wave drawn is referred to as the fundamental. Usually higher frequency waves are added to a fundamental.

Harmonic: A wave that has a frequency which is an integer multiple of the fundamental's frequency.

Fourier synthesis: The formation of complex waves by the addition of harmonics to the fundamental. It has been shown that any periodic wave can be 'constructed' by adding just the right amplitude of specific harmonics. This program will demonstrate, for example, the synthesis of an approximately square wave by adding 4 harmonics to the fundamental.

WAVE ADDITION II

TEACHER'S GUIDE

This program was designed to be used either for teacher demonstrations or by small groups of students working independently. Several interesting consequences of wave superposition, which are difficult to illustrate on a chalkboard, can be demonstrated using this program. Specific suggestions for use are given below:

1. Teaching terminology of waves

The terms wavelength, frequency, amplitude, phase angle, phase difference and others can be demonstrated using the program. Beginning physics students will probably better understand these terms after experimenting with this program.

2. The relationship between wavelength, frequency and velocity

Wavelength and wave velocity are not specifically mentioned in the program. However, the wavelength of a wave can easily be measured using the linear scales which are drawn on the screen. Remember that the tick marks along the center line and the vertical line are 10 units apart. Students should be able to deduce the relationship between frequency and wavelength. The wave speed can also be calculated. The wave speed is set up as equal to 800 units/sec. This can be shown by measuring the wavelength of any wave and multiplying by the frequency. For example, using the fundamental:

wave speed = wavelength * frequency

= 80 units * 10 Hertz = 800 units/sec

3. Constructive and destructive interference

Using mode 2, these two concepts are easily demonstrated. Show constructive interference by adding two waves of the same frequency and with the same phase angle. Show destructive interference by adding two waves of the same frequency and differing in phase by 180 degrees.

4. Beats

The graphic display in this program is intended to represent displacement vs. distance along the wave. It can, however, just as well be used to represent a displacement vs. time graph for a particular location. If the graph is interpreted in this way, mode 3 illustrates the formation of beats. Two waves of the same amplitude, but slightly different wavelengths (and frequencies), are added together. The result is a periodic wave whose amplitude varies in time. This is what we hear as beats. Only about one cycle of the variation in amplitude is shown on the screen. You can then redraw the waves on the expanded scale (by entering an "E") to show how this pattern continues. Students should be able to appreciate how the variations in amplitude occur if they are shown how the two waves being added change from being out of phase to in phase.

Using the expanded version of the diagram, the "beat frequency" of the summation wave can be determined. The "beat wavelength" of the summation wave can be measured on the diagram by noting the horizontal distance between the points of maximum amplitude. This is about 270 units. Since the wave speed is known to be 800 units/sec (see number 1 above) the beat frequency must be:

$$\text{frequency} = \frac{\text{wave speed}}{\text{wavelength}} = \frac{800}{270} = 3.0 \text{ Hertz}$$

This, of course, is the difference in the frequencies of the two waves which were added to produce the beats. By using mode 2 and selecting other frequencies to add and produce beats this can be shown for other cases.

Further discussion could include the mathematical formula for the summation wave.

5. Interference of periodic waves

Using modes 2 and 4 it is easy to verify that:

-- The superposition of any number of periodic waves of the same frequency, but different amplitudes and phase angles, always yields a simple sinusoidal wave with the same frequency. Several "EXEC" files have been set up to expedite this demonstration. The use of EXEC files is described at the end of this Teacher's Guide.

-- The superposition of waves of different frequencies yields a complex wave.

-- The 'shape' of the summation wave may be affected by the phase difference.

6. Approximating the 'shapes' of the waves produced by musical instruments

Diagrams showing the 'shapes' of the waves produced by specific musical instruments are often included in physics texts. They can also be easily demonstrated using an oscilloscope. These shapes can usually be produced approximately with this program. Normally only the first 4 or 5 harmonics are needed. Here are some specific examples taken from Physics, by Halliday and Resnick, 1960 Edition., p. 506:

INSTRUMENT		AMPLITUDE
Piano	2nd harmonic	8 units
	3rd	10
	4th	5
	5th	5
Violin	2nd harmonic	40 units
	3rd	17
	4th	20
	5th	40

See also College Physics, Sears and Zemansky, 3rd Edition, p. 438.

EXEC files have been included on this diskette to automatically demonstrate these two waves. See the section on EXEC files below.

7. Fourier synthesis

Modes 6 through 9 demonstrate the principle of Fourier synthesis. Many students have heard of this concept, but have never really seen it demonstrated. Modes 6, 7 and 8 produce nice approximations of sawtooth, square and triangular waves respectively. Mode 9 allows you to experiment with your own values for the amplitudes of the harmonics. Theoretically, you should be able to approximate any shape of periodic wave (especially if you increase the number of waves to be considered, as is explained in the modifications section of this manual).

The use of special option "T" is recommended when using modes 6 through 9. With this option you can observe the gradual change in the summation wave as additional harmonics are added. The graphics on the page following the Teacher's Guide illustrate the results of using mode "7T" to study how the square wave approximation improves as more harmonics are added.

DEMONSTRATIONS USING EXEC FILES:

Several EXEC files are included on the diskette to help you demonstrate some of the phenomena discussed above. An EXEC file takes control of the computer and makes the appropriate entries to produce a demonstration on the screen. The following EXEC files are available:

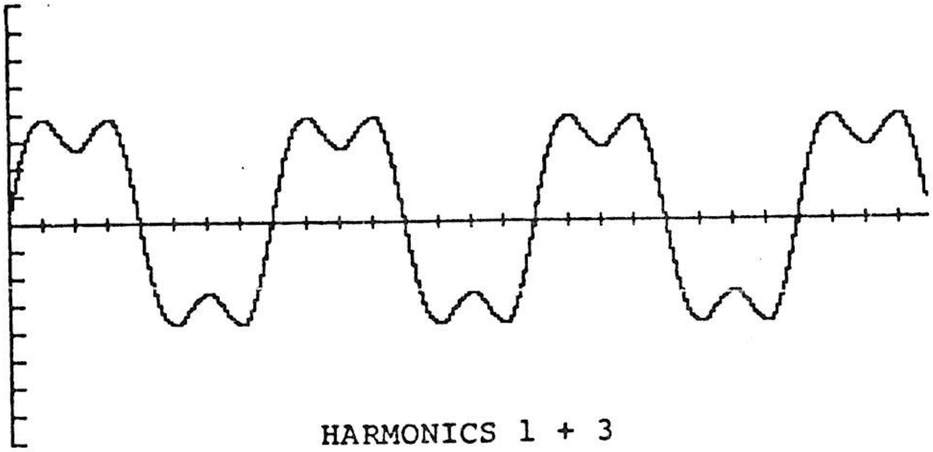
PIANO WAVE	Synthesis of a piano wave
VIOLIN WAVE	Synthesis of a violin wave
SF1 SF2 SF3	Demonstrate the addition of 4 waves of the same frequency

DF1
DF2 Demonstrate the addition of 4 waves of different frequencies
DF3

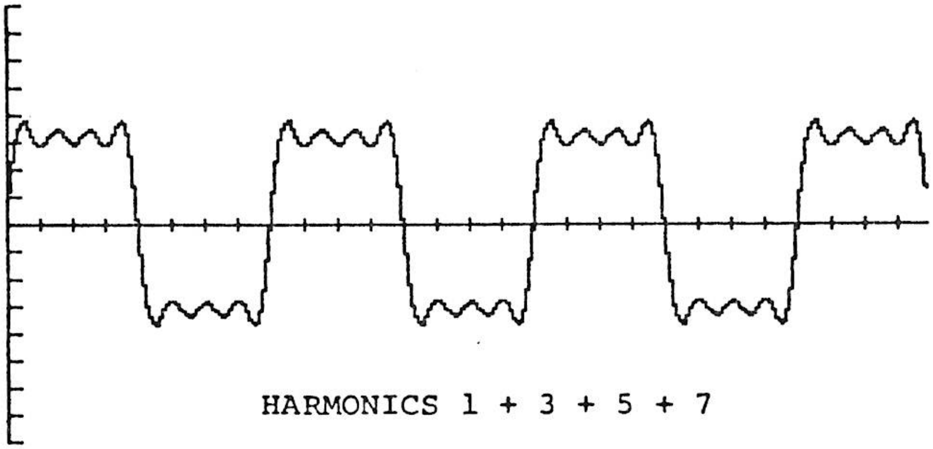
To use one of these EXEC files, start up the program as usual, break out of the program by selecting mode 10 from the main menu (or entering "CONTROL C"), and then enter "EXEC name" where "name" is the name of the file you wish to execute. The EXEC file will take control of the computer and generate the appropriate wave addition diagram.

If you have any problems or questions about this program, please contact us.

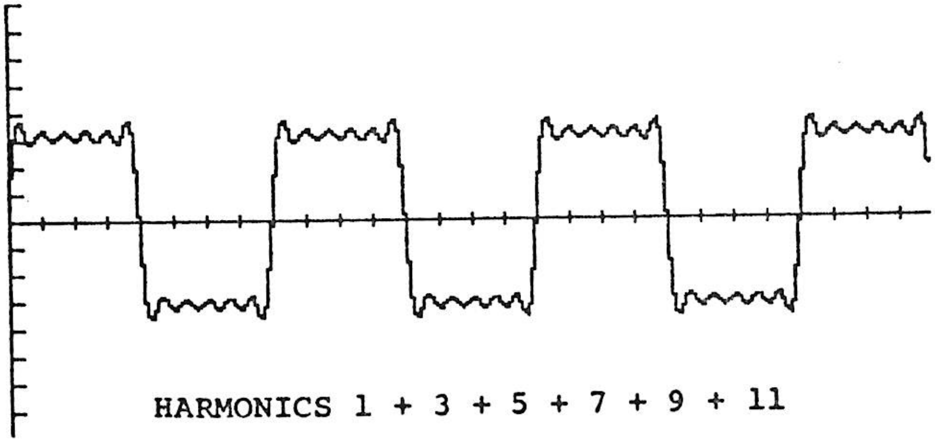
Vernier Software
2920 S.W. 89th Street
Portland, OR 97225
(503)297-5317



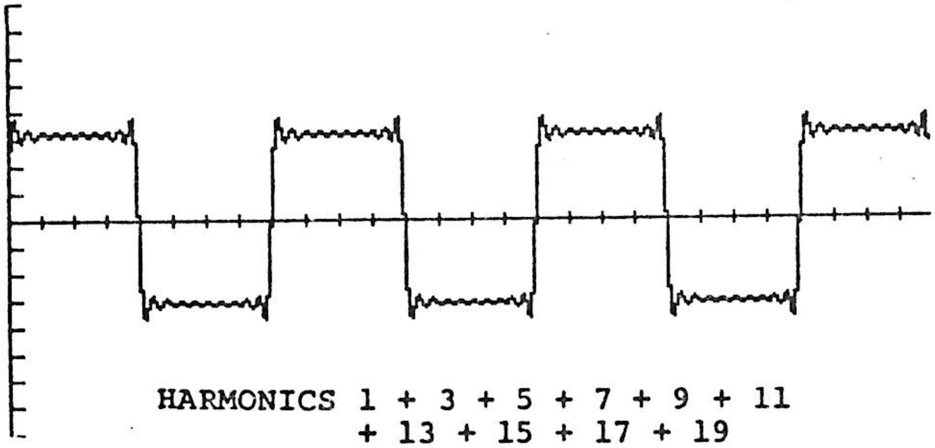
HARMONICS 1 + 3



HARMONICS 1 + 3 + 5 + 7



HARMONICS 1 + 3 + 5 + 7 + 9 + 11



HARMONICS 1 + 3 + 5 + 7 + 9 + 11
+ 13 + 15 + 17 + 19

APPENDIX A - COMPILED VERSION OF THE PROGRAM

A compiled version of this program has been included on the diskette. In fact, this version of the program will run automatically when you "boot" the diskette. You will probably want to use this version of the program instead of the normal Applesoft BASIC version (which is also on the diskette). You should use the normal BASIC version of the program if you want to modify the program for your own specific uses. A normal BASIC program is translated line by line into machine language as it runs. This is a time consuming process. When a BASIC program is compiled, it is translated completely into a machine language version which is then BRUN. The principal advantage of a compiled program is that the program runs quite a bit faster (often 2 or 3 times faster). There are some disadvantages in using the compiled version:

- The compiled version cannot be listed.
- The compiled version of the program cannot be easily modified since it is not in BASIC.
- A CTRL C during program execution will have no effect. Entering CTRL C as an input will interrupt the program as it would normally.
- After a program has been interrupted (with a RESET or a CTRL C), the program cannot be restarted by simply typing RUN. If you exit the program and want to run it again, type "&" and press return.

If you want to use the normal BASIC version of this program, RUN the HELLO.B program. This short program will set things up and then run the Applesoft BASIC version of the program.

If you want to change the disk so that the normal BASIC version of the program will run automatically when the disk is booted, follow this procedure:

Type:
```
RENAME HELLO, HELLO.C
RENAME HELLO.B, HELLO
```

This will change the greetings program which is run when the disk is booted to HELLO.B. The normal HELLO program is saved with the name HELLO.C.

APPENDIX B - PHYSICS UTILITY PROGRAMS

Three short programs which might be useful in your science classes have been added to this diskette. They are described briefly below:

1. LARGE PRINT: This program is a simple demonstration of a subroutine which you might want to use in your own programs. It prints any number you enter (including negatives and scientific notation) in large digits, which a whole class should be able to read. The subroutine is in lines 50000 - 60000. The two programs described below use this large print subroutine.

2. BINARY: This program is designed to assist a teacher in explaining the binary number system. The program allows you to enter a number between 0 and 255 and have it displayed in three ways: as a decimal number, as a binary number and as a binary bit pattern in a series of 'on' or 'off' lamps. If the number 256 is entered, the computer will "count", displaying the numbers from 0 to 255 in order.

3. CALCULATOR: This program allows you to use the computer as a simple four-function calculator which displays all numbers entered and results in large digits for the whole class to see. You may find this program useful in going over homework or doing demonstration problems.

WAVE ADDITION II

MODIFICATIONS YOU MIGHT WANT TO TRY

The changes below can be made to the BASIC version of the program:

1. Change fundamental's parameters (F(1),A(1),P(1) in line 30088)

The fundamental used in all modes was selected as a compromise giving pretty good graphic displays in all modes. If you wish, however, you can change the fundamental values in line 30088.

2. Change detail of graphics (D in line 30080)

The constant D controls the detail of the graphics in the drawing of the waves. It is set equal to one. You can speed things up, but lose some detail on the graphics, by increasing D to 3. You may want to do this to speed things up if you use the BASIC version of the program.

3. Increase the number of waves added in modes 6, 7, 8, 9 (R in line 30070)

Normally, only the first 9 harmonics are considered in this program. It might be interesting to improve the approximation of the Fourier synthesis by allowing more harmonics to be added. Of course, this will take longer. Change the value of R in line 30070. Modes 1-5 will not be affected. If you increase G to more than 20 you will also have to change line number 30085.

4. Change the number of waves drawn in modes 6, 7, 8, 9 (G in line 30075)

You do not have to have the computer draw every wave which it uses in the superpositioning. For example, you might want the computer to superpose 9 waves, but only draw the first 4 to speed things up and avoid cluttering the screen. This might also be useful if you make modification 3. If you want to change the number of waves graphed, change the value of G in line 30075. Modes 1-5 will not be affected.

5. Allow the input of the phase angle in mode 9

As written, mode nine allows only the input of the amplitude of each harmonic. The phase angle is always set to zero. If you want to make this mode more flexible, add this new line to the program:

```
9065 PRINT  "ENTER PHASE ANGLE OF HARMONIC #";J : INPUT P(J)
```

WAVE ADDITION II

PROGRAM DESIGN NOTES

FILES:

The following files are included on this diskette:

HELLO: Displays the logo and runs the compiled version of the program.

HELLO.B: Displays the logo and runs the BASIC version of the program.

WAVE ADDITION II: The standard BASIC version of the program. It will not run properly if simply RUN. It be must first set up using the HELLO.B program.

WAVE ADDITION II.OBJ: The compiled version of the program. It must be set up with the HELLO program.

RUNTIME: This is a library of machine language subroutines used in the compiled version of this program.

WAVE ADDITION LOGO: This is the Vernier Software Logo for the WAVE ADDITION II program.

G1, G2, G3, G4: These are four high resolution graphics screens which contain the general instructions for using the program. They are BLOADED into page two of high resolution graphics.

EXEC FILES: The disk also includes a series of EXEC files which may be executed to automatically produce a wave superposition diagram.

MEMORY ORGANIZATION:

The main WAVE ADDITION II program (either BASIC or compiled) is always loaded above page 2 of the high resolution graphics starting at 24576 ($6000). This is to avoid the problem of the program overflowing into the graphics memory usage. Both high resolution screens are used for graphics. Page two of text is loaded at $800. As noted above, the BASIC version of the main program will not operate properly if simply RUN. This is because it will conflict with the graphics and page two of text. The HELLO.B program sets pointers to eliminate this problem.

ROUTINES:

The WAVE ADDITION II program is made up of a short program (lines 100 - 495) which calls a number of routines. These routines are explained below:

LINE NUMBERS	ROUTINE
500 - 590	ENTER WAVE PARAMETERS
600 - 640	DRAW BACKGROUND LINES AND TICK MARKS
648 - 998	DRAW A COMPONENT WAVE
1000 - 1999	SET UP MODE 1
2000 - 2999	SET UP MODE 2
3000 - 3999	SET UP MODE 3
4000 - 4999	SET UP MODE 4
5000 - 5999	SET UP MODE 5
6000 - 6999	SET UP MODE 6
7000 - 7999	SET UP MODE 7
8000 - 8999	SET UP MODE 8
9000 - 9999	SET UP MODE 9
10000 - 10800	DRAW RESULT OF SUPERPOSITION
20000 - 20990	DISPLAY GENERAL INSTRUCTIONS SCREENS
30000 - 30900	INITIALIZE CONSTANTS

DRAWING THE WAVES:

The component waves used in this program are drawn using the formula:

Y = A(J) * SIN (K * X + PR)

where:

Y = vertical displacement
A(J) = amplitude of the wave
K = wave number of the wave = $\frac{\text{2 * pi * frequency}}{\text{wave speed}}$
X = horizontal displacement
PR = phase angle of the wave

after the Y values are calculated, the actual plotting is done using a variable YP which is the adjusted y value defined as: YP = 80 -Y. In this way, Y shows up on the screen as a distance from the center line. As written, component waves are calculated and plotted for each integer value of x. In the same loop that does the plotting of the component waves the displacements are added to the values in SY(X). This array contains the displacements of the summation wave for each value of X. Later in the program the values of SY(X) are used to plot the summation wave.

When the waves are drawn using the expanded graphics, the tick marks are placed at half the distance apart so that they still represent 10 units. The wave number is doubled, which has the effect of cutting the wavelength as drawn in half. The waves are then calculated and drawn as before.

This information is provided to make it easier for you to modify WAVE ADDITION II for your own special purposes. The program is not copy protected. The listing has many REM statements to help you understand the program operation (although they had to be kept somewhat limited to save execution time and memory space). Please respect our copyright on this program.

Vernier Software
2920 S.W. 89th Street
Portland, OR 97225
(503) 297-5317

WAVE ADDITION II

TABLE OF VARIABLES

D$ = CONTROL D (used for disk access)
J = LOOP COUNTER INDICATING THE NUMBER OF THE HARMONIC
CO = GRAPHICS COLOR SELECTOR
Q$ = DUMMY INPUT STRING
M$ = MODE SELECTION STRING
M = MODE OF OPERATION
SF = STOP OPTION FLAG
TF = TOTAL OPTION FLAG
EF = EXPANDED SCALE FLAG
ST = DISTANCE BETWEEN TICK MARKS
F() = FREQUENCY
A() = AMPLITUDE
P() = PHASE ANGLE
V = WAVE VELOCITY
K = WAVE NUMBER
X = X-COORDINATE OF WAVE
Y(X) = Y-COORDINATE OF WAVE AT EACH X-COORDINATE
SY(X) = Y-COORDINATE OF THE SUMMATION WAVE AT EACH X-COORDINATE
ZE = ZERO (smallest YP that can be plotted)
MY = 159 (largest YP that can be plotted)
TWOPI = 2 * 3.1415
D = STEP SIZE (determines the detail of the graphics)
M9 = LOOP COUNTER FOR DRAWING LINEAR SCALES
R = NUMBER OF WAVES TO BE ADDED
G = NUMBER OF WAVES TO BE GRAPHED